SIMULATION AND VERIFICATION MOLD TEMPERATURE VARIATION OF PULSED-COOLING

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Abstract

Nowadays most products need high quality of surface appearance which can be achieved usually at high mold temperature. Pulsed cooling is one of the variable mold temperature controls without significant increase in cycle time. In this study, pulsed cooling was applied in the injection and packing process for about 0.3 seconds and mold temperature can be higher than that conventional injection molding by about 5℃. The mold temperature can also be lowered down efficiently in the cooling process. Simulation based on Moldex3D® was carried out and simulated predictions show similar trend in mold temperature rise and in fair coincidence with the experimental results.

Introduction

As 3C(Computer, communication, consumer electronic)products progress along with the technology improvements, the basic characteristics are still less weight, thin shell, and fancy outfits. However, thin shell products must come along with larger flow drag and therefore products are affected by the temperature. Furthermore, as design cycle time getting shorter and shorter, more runners are usually adopted to speed up the production. However, this induces the problem of strength of the structure, like seam lines and residual stress. The structures close to seam lines are weaker than others. And residual stresses make products easier to be damaged under impact. Therefore in order to avoid the defect, the ordinary solution is to raise mold temperature to lower the melt's viscosity and improve the flow ability. In this way, it takes longer for the molecules to crystallize and therefore the product quality can be improved significantly. The strength of the seam line can also be improved enormously because the compound degree between the long molecules is increased by the higher molding temperature.

Although the quality can be improved with this process parameters, the problem is increased due to longer cooling time. In order to keep the merit of high mold temperature and avoid the cycle time increase, the dynamic control of mold temperature is adopted to tackle all the problems. The dynamic control of mold temperature include flame heating, induction heating, molder inside coating and pulse cooling. This technology provides an instant high temperature only on the mold surface to increase the flow ability of the melt in the filling stage. In the cooling stage, the temperature can be lowered down quickly and not affecting the cycle time due to the fact that high temperature is only restricted on the surface area of the mold. This method can effectively control the temperature history and therefore be able to specify the process parameters and switch time. It's definitively a big boost for the injection molding industry.

Research methodology

In the hardware system, this research modified the traditional molding machine controller to a machine equipped with pulse cooling capability. There are two main functions in the control system: one is to switch independently to adapt to the tensile specimen mold and temperature sensor system. The other is to measure the complete temperature history.

The data of the temperature history is used, after the process is stable, to control the raising of temperature and maximum temperature of each cycle. For the raising the temperature of each cycle, the main purpose is to understand the increase of flow ability with the increase of mold temperature during the filling stage; On the other hand, for the maximum temperature control, this method is able to measure the result that even the temperature is lower than the traditional mold cooling design, the temperature raising effect is still the same and energy saving can be achieved.

The experiment will be done according to the process parameters of table 1, including the changing material and molding temperatures. The temperatures are picked up by inserting the thermal couples in the region only 1mm distance from the mold surface (fig 3) and recording the temperatures histories for both pulse and traditional cooling. The largest difference is the cooling water of pulse cooling will stay in the mold. This result in the heat stagnation effect of the mold due to heat extracted from cooling water is decreased and melt heat up the mold. In the mean time, the same process parameters are adopted in the Moldex3D®, the analysis model is built as the same as the real mold, and the material and parameters are also the same as in the experiment (fig 4). The parameters and the materials used in the analysis are also the same as in the experiment. TheAD-5503 produced by Teijin is set up. The results from the analysis are compared with the experiment to see if the trend is correct. The reality of the temperature history is also studied in an analytical way to see if the results are compatible with the experiment.

Results and Discussions

In the results of incorporating different process parameters, the final stabilized maximum temperature can be observed to increase with the mold and material temperatures (fig 5). Although the scale is not significant, there is a clear trend in the data to prove that the mold temperature can be raised about 3~5C if pulse cooling is adopted. On the other hand in the traditional cooling with different process parameters, the final stabilized maximum temperature is observed to increase in the range 2~2.4C in one cycle. That is, the temperature raised by pulse cooling is slightly higher than the traditional cooling.

From the data analysis (fig 7 and 8), the differences between pulse and traditional is not significant, less than 0.1. However, the numerical data and the trend are very similar to the results of our experiments. After it is stabilized, the data comparison between experiments and numerical analysis shows that the maximum temperature of the pulse cooling is indeed higher than the traditional cooling(fig 9 and 11), although the difference is small. For one cycle, the temperature raising shows the same result between experiment and numerical analysis, as the same conclusion drawn from the maximum temperature (fig 10 and 12). Furthermore for the entire mold temperatures, due to the unsymmetrical design of coolant pipes, there are some temperature differences between core and cavity side of the molds (fig 13 and 14). However, the numerical analysis only shows average temperatures. Therefore the differences between core and cavity side of the molds is not significant. Based on the information above, the experiment design and numerical analysis are correct, therefore the process parameters can be determined before this manufacturing process is used.

Conclusion

Because coolant doesn't take much heat out in the filling stage of the pulse cooling, the plastic's heat can be transferred to the surface of the mold. This ensures higher temperature in the filling of the plastic, improves replication accuracy, structural strength and surface quality, etc. Therefore the purpose of this study is accomplished. For the temperature raising of one cycle, the results show that if the coolant temperature are kept the same and flow cross section and distance are kept constant, from the heat transfer formula, the mold with higher temperature will take away more heat:

$$\dot{Q} = -\lambda A \frac{dT}{dx}$$

Therefore pulse cooling is more efficient than the traditional cooling in the same cooling time. Besides, for the results of one cycle temperature raising, the temperature from pulse cooling is only 0.1~0.2℃higher than the traditional cooling. The reason comes from the design of coolant pipe. If the coolant pipe is designed to be uniformly distributed over the product, the better heat stagnation than the traditional cooling can be achieved. This results in higher process mold temperature in the filling stage.

In the results comparison of numerical analysis, although the trend of maximum temperature and the temperature raising of one cycle is the same as the experiment, the difference between pulse and traditional cooling is very small. This means the coolant pipe design is not good and it is confirmed in the numerical analysis. The same trend of the experiment and the numerical establish the strong credibility of the software, and it also confirms the experimental results.

References

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Table 1.Process parameters

Process parameters	
Filling time	0.18 (s)
Packing time	0.2 (s)
Cooling time	15 (s)
Cycle time	24 (s)
Injection speed	300 mm/s
Ejection pressure	150 MPa
Packing pressure	120 MPa
Melt temperature	330, 345, 360 ℃
Mold temperature	84, 99, 114 ℃

Table 2.Experimental method

	Mold temperature	**Melt temperature**	**Process**
A1	84	330	Tradition
A2			Pulse
A3		345	Tradition
A4			Pulse
A5		360	Tradition
A6			Pulse
B1	99	330	Tradition
B2			Pulse
B3		345	Tradition
B4			Pulse
B5		360	Tradition
B6			Pulse
C1	114	330	Tradition
C2			Pulse
C3		345	Tradition
C4			Pulse
C5		360	Tradition
C6			Pulse

Figure 1.Tensile specimen mold

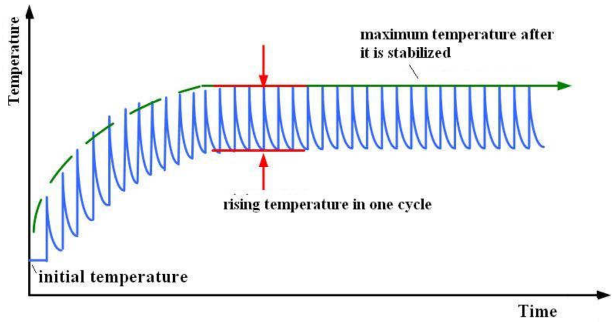

Figure 2.The illustration of the maximum temperature of one cycle temperature rising after it is stabilized

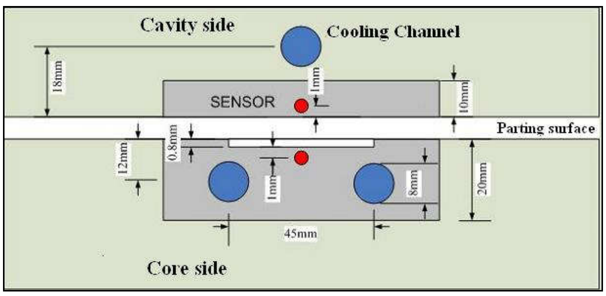

Figure 3.The sensor location (in red)

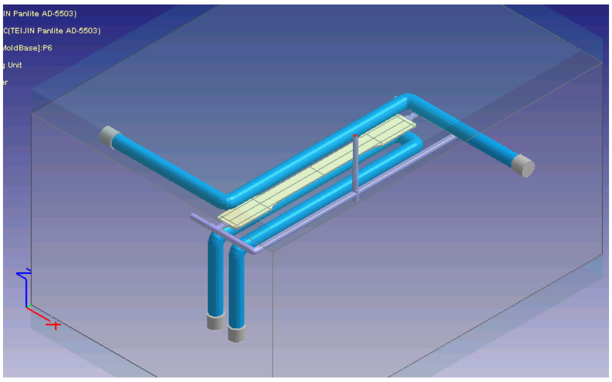

Figure 4.Moldes3D's mesh results

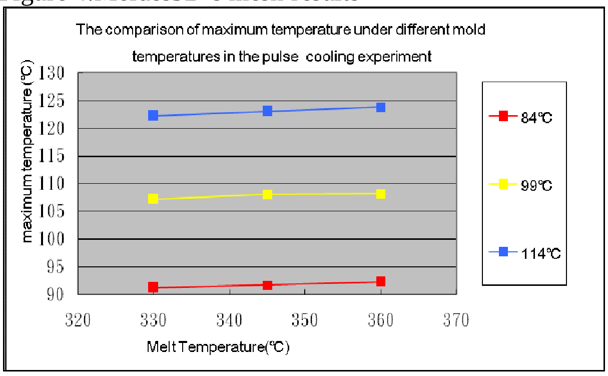

Figure 5.The comparison of maximum temperature between mold and plastic in the pulse cooling experiment.

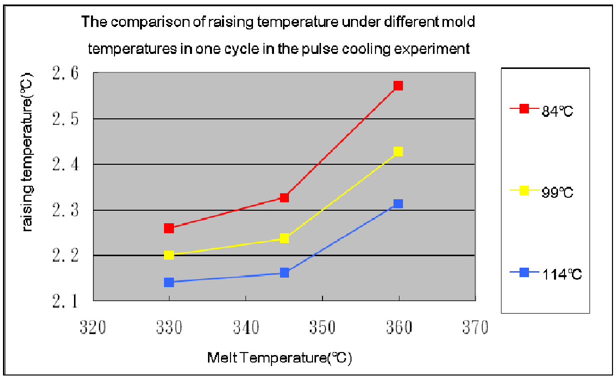

Figure 6.The comparison of raising temperature between mold and plastic in one cycle in the pulse cooling experiment.

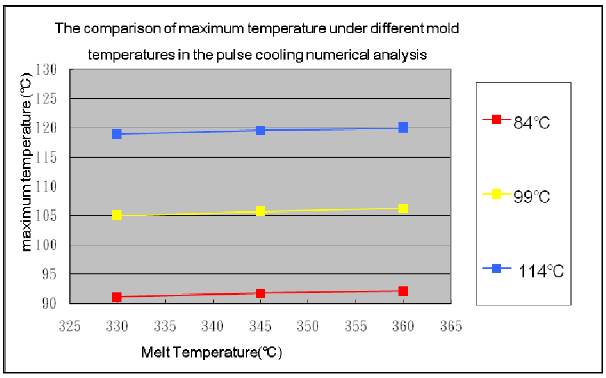

Figure 7.The comparison of maximum temperature between mold and plastic in the pulse cooling numerical analysis.

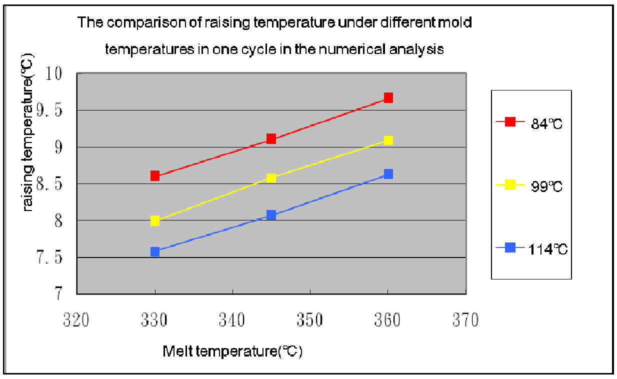

Figure 8.The comparison of raising temperature in one cycle between mold and plastic in the numerical analysis.

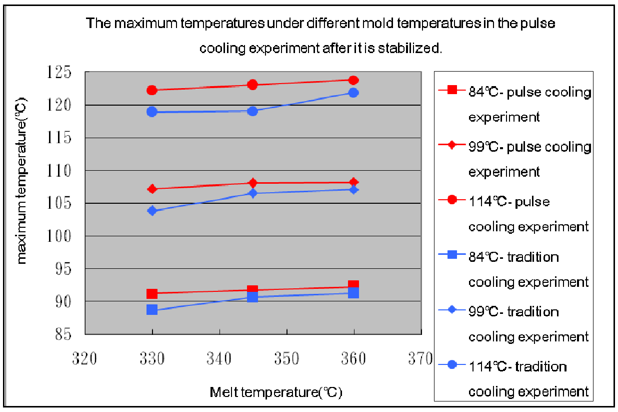

Figure 9.The maximum temperatures in the pulse cooling experiment after it is stabilized.

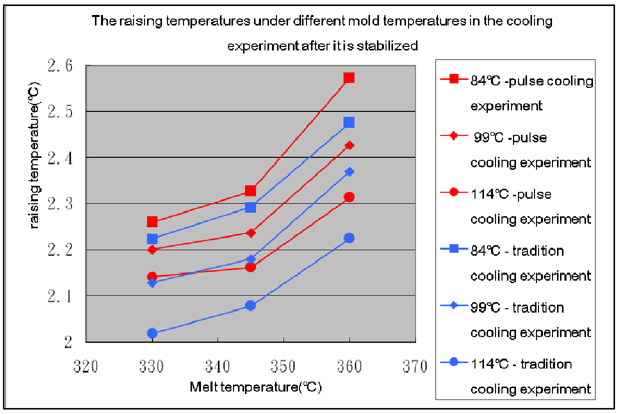

Figure 10.The raising temperatures in one cycle of the pulse cooling experiment after it is stabilized.

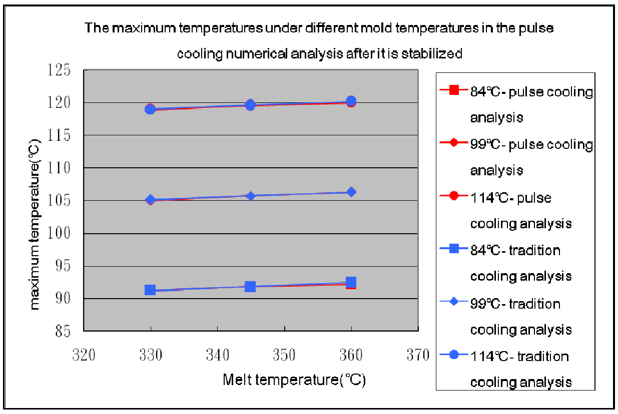

Figure 11.The maximum temperatures in the pulse cooling numerical analysis after it is stabilized.

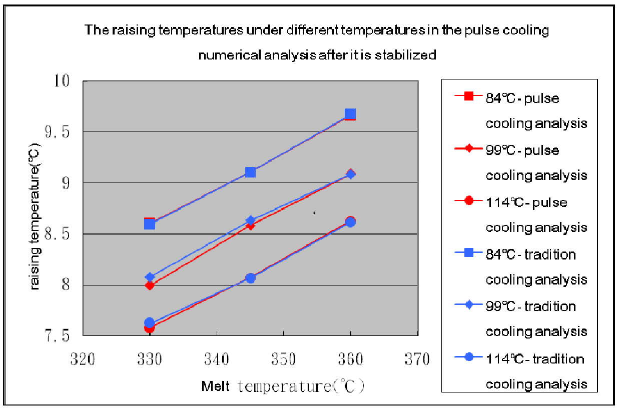

Figure 12.The raising temperatures in one cycle of the pulse cooling numerical analysis after it is stabilized.

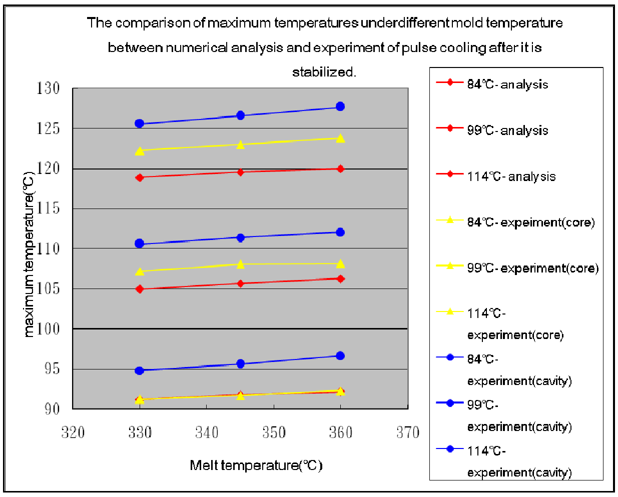

Figure 13.The comparison of maximum temperatures between numerical analysis and experiment of pulse cooling after it is stabilized.

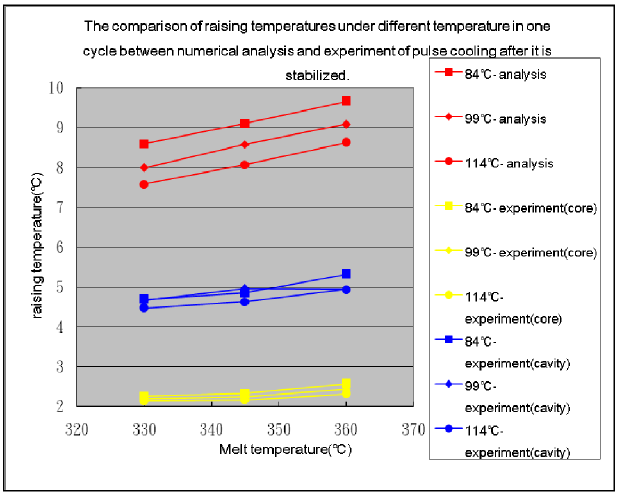

Figure 14.The comparison of temperatures raising in one cycle between numerical analysis and experiment of pulse cooling after it is stabilized.

Key Words: Pulse Cooling, varothermal technology, Dynamic mold temperature control.